

FINAL TECHNICAL REPORT for NASA Grant NNG04GD97G

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Period Covered: 02/15/04 - 02/14/05

Title: Connection Between X-Ray Dips and Superluminal Ejections in the Radio Galaxy 3C 120

Overview

This work represents a part of a longterm study of the X-ray flux variability of 3C 120 and its relation to flux and structural changes in the radio jet of this galaxy. The grant included funding for the reduction and analysis of data obtained during the time period of Rossi XTE cycle 8 (March 1, 2003-February 29, 2004). Prior RXTE observations, combined with single dish monitoring at centimeter wavelengths and 43 GHz mapping (monthly until February 1999 and bimonthly thereafter) of the inner jet with the VLBA, had identified the presence of X-ray dips in the light curves and X-ray spectral hardening 4 weeks prior to the ejection of new VLBI components in the radio jet (Marscher et al. 2002, *Nature*, 417, 625). This suggested a picture in which the radio jet was fed by accretion events near the black hole. The specific goals of the cycle 8 observations were to better define the relation between the X-ray dips and the radio events using higher sampling, to include more events in the correlation and hence improve the statistics, to look for a possible optical X-ray connection, and to search for quasi periodicities on timescales of 1-3 days. In cycle 8 this project was awarded time for 4 pointings weekly with RXTE. This award is a subgrant; A. P. Marscher (BU) is the project PI.

Results From Grant Period

The X-ray data, including those from earlier cycles, were compared with frequent single-dish radio measurements obtained in the centimeter-wave band (14.5, 8.0, and 4.8 GHz) with the 26-m paraboloid at the University of Michigan Radio Astronomy Observatory (UMRAO), with monitoring data from the Metsähovi Radio Observatory in Finland at 22 and 37 GHz, and with monthly imaging observations with the VLBA at 43 GHz. Observational results from the program are shown in Figures 1 and 2. The highest frequency single-dish radio data ($\nu \geq 14.5$ GHz) are particularly useful in identifying changes in flux amplitude: opacity is well-known to suppress the variations at lower radio frequencies.

The full RXTE data set includes eight significant X-ray dips that precede the “time of ejection” of a new component in the VLBA images (or coincidence of the moving feature with the core at the narrow end of the radio jet) by ~ 60 days. Our interpretation of the link between radio events and the X-ray events is analogous to that for the galactic superluminal GRS 1915+105 where X-ray dips are thought to be caused either by an instability breaking off a piece of the inner accretion disk, which then falls into the black hole, or by alignment of the magnetic field toward the polar direction. Each of these would cause a decrease in the energy converted to X-ray emission, accompanied by a burst of energy down the jet (actually, jets, since there is a counterjet made invisible by relativistic

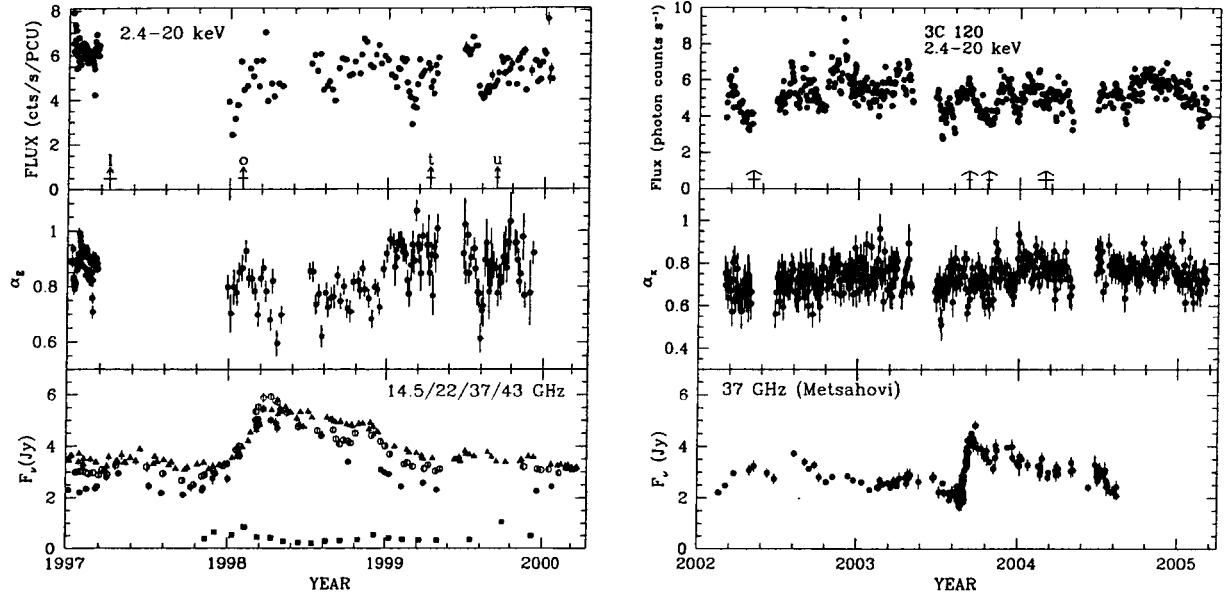


Fig. 1. X-ray light curve and variation of the X-ray spectral “energy” index of 3C 120 and radio band fluxes. The times when a new, bright superluminal knot appeared at the radio core are marked by vertical arrows, with the uncertainties noted by horizontal bars.

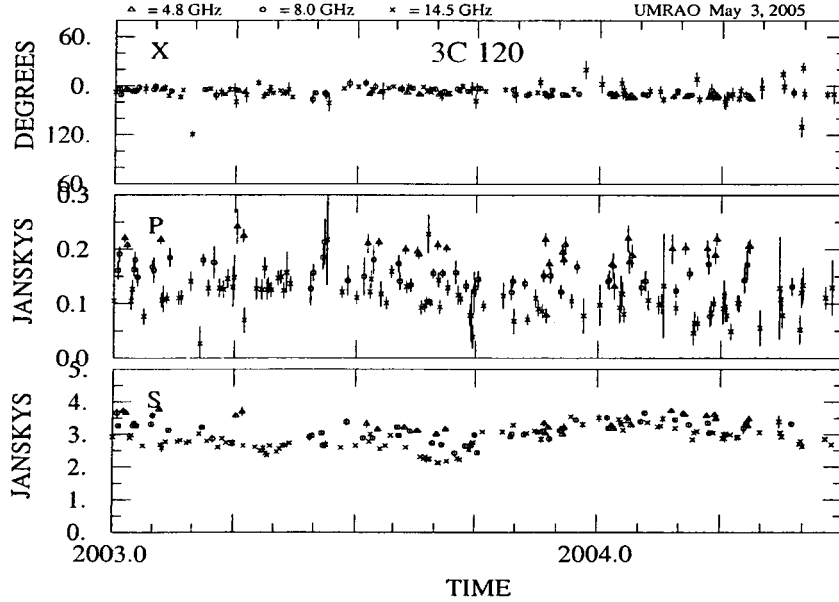


Figure 2. Daily averages of the University of Michigan total flux monitoring data obtained during cycle 8. The panels show from bottom to top total flux density, polarized flux, and the electric vector of the polarized emission (direction orthogonal to the magnetic field direction in the radio emitting region assuming no Faraday rotation). The rise in total flux density in mid 2003 dramatically seen in the Metsähovi data in the right panel of Figure 1 is also apparent in the UMRAO 14.5 GHz data, with reduced amplitude. A temporally associated dip in polarized flux at 14.5 GHz followed by a rise is consistent with the ejection of a new VLBI-scale component at this epoch.

beaming). When this disturbance travels past the radio core, a superluminal knot is seen. The observed delay implies that the radio core is at least 0.4 pc downstream of the black hole. On a radio image, the angular distance between the two ~ 0.2 milliarcsec, projected on the plane of the sky. This constrains models of the innermost regions of relativistic jets, requiring either acceleration out to parsec scales or the presence of a region where energization of relativistic electrons is inhibited close to the black hole/accretion disk system.

While the primary project goals were attained, analysis of the power spectrum of the X-ray data, unfortunately, revealed no significant periodicities in the flux variability of 3C 120, in contrast with the quasi-periodicities seen in microquasars. Also, the optical data acquired in this cycle were too infrequent to make a meaningful comparison with the radio and X-ray variations; these are difficult measurements requiring careful subtraction of the contribution to the optical flux from the galaxy component. We expect that future observations at Lowell and with the Liverpool Telescope at La Palma will provide the data required for us to make this comparison robustly.

There were no patents or inventions resulting from the work supported by this grant, and no equipment was purchased. The following publications describe RXTE results for 3C 120 resulting from this project. Acknowledgments for NASA funding are included therein where appropriate.

Publications

- Marscher, A.P. "Relativistic Jets in Blazars: Where the Action Is," 2003, in *Radio Astronomy at the Fringe*, ed. J.A. Zensus, M.H. Cohen, and E. Ros, *Astronomical Soc. Pacific Conf. Ser.*, **300**, 133–140.
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- Marscher, A.P., Jorstad, S.J., Aller, M.F., McHardy, I.M., Balonek, T.J., Terasranta, H., and Tosti, G. "Relative Timing of Variability of Blazars at X-Ray and Lower Frequencies," 2004, in *X-Ray Timing 2003: Rossi and Beyond*, ed. P. Kaaret, F.K. Lamb, and J.H. Swank, *AIP Conf. Proc.*, **714**, 167–173.
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- Marscher, A.P., and Jorstad, S.G. "3C 120 and the Disk-Jet Connection," 2005, in *AGN Variability from Radio to X-rays*, ed. C.M. Gaskell *et al.*, *Astronomical Soc. Pacific*

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Marscher, A.P. "The Relationship between Radio and Higher-Frequency Emission in Active Galactic Nuclei," 2005, in *Multiband Approach to AGN*, ed. A. Lobanov, *Memorie della Societa Astronomica Italiana*, in press.

Marscher, A.P. "Multiband Impressions of Active Galactic Nuclei," 2005, in *Multiband Approach to AGN*, ed. A. Lobanov, *Memorie della Societa Astronomica Italiana*, in press.